Aerodynamics of low-rise buildings: large-scale open-jet testing to address Reynolds number effects

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ABSTRACT:
Wind flow over low-rise buildings in the atmospheric boundary layer (ABL) is accompanied by some complex flow physics such as flow separation and generation of vortices in the shear layer. The uncertainties associated with such complex flow mechanisms make the case-by-case experimental or numerical investigation of buildings' aerodynamic behavior fundamental. Engineers have aspired to replicate the full-scale real wind behavior in wind-tunnels to create more resilient infrastructures. Traditional wind-tunnel experiments struggle to accurately predict surface pressures despite being widely embraced by the structural engineering community. This limitation is attributed to the lack of large-scale turbulence and low Reynolds numbers in wind-tunnels. Such drawbacks prompted the consideration of aerodynamic testing by the open-jet concept. Open-jet experiments of building models with higher Reynolds numbers reveal the generation of higher mean and peak pressure coefficients, compared to those obtained from wind-tunnels; the findings reinforce the initial hypothesis.

Keywords: Bluff body, Atmospheric boundary layer (ABL), Wind-tunnels, Open-jet, Turbulence, Reynolds number.

1. INTRODUCTION

The human activity-induced phenomenon, global warming, is indirectly making powerful hurricanes more frequent in the South-Eastern coast of the United States. Hurricanes are the costliest natural disasters in the United States. The most common source of economic losses stems from widespread damages to low-rise buildings. An estimated gross economic loss worth up to \$265 billion was recorded due to hurricanes Irma, Maria, and Harvey [1]. In the majority of the cases, damages initiate from the building's envelope, especially, the roof. Roofs experience extreme negative pressures as strong winds separate at or near buildings' leading edges, corners, and ridges. The partial or total failure of the roof and its components leave the entire building extremely vulnerable to powerful winds by allowing internal pressure to increase. Therefore, accurate estimation of surface pressures is crucial to improve buildings' resiliency against powerful windstorms. The unpredictable and complicated nature of turbulent winds makes aerodynamic loads' prediction a challenging task. The accuracy of such load prediction depends on the exactness of replicating the turbulence intensity, integral length scale, and Reynolds numbers. The ideal scenario is to reproduce the features of full-scale real-wind in the laboratory. Furthermore, for precise load-prediction, it is important to ensure small and large-scale turbulence in the incident flow. In other words, the laboratory should be able to reproduce both low-frequency (large-scale) and high-frequency (small-scale) velocity fluctuations with adequate energy. In wind-tunnels, the low-frequency turbulence does not possess sufficient energy; consequently, such experiments fail to produce large-scale turbulence in the laboratory. This limitation contributes to the difference in the estimation of peak pressure coefficients from wind-tunnels and the

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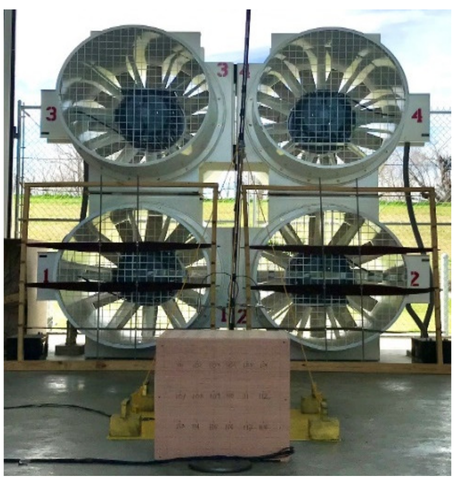
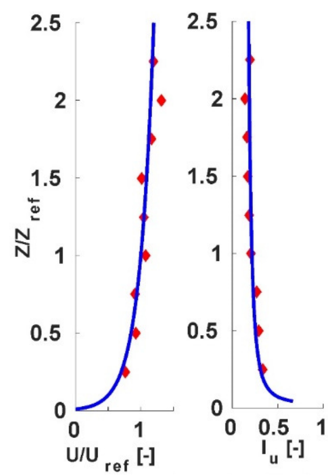
corresponding full-scale scenario [2]. Aerodynamic testing at higher Reynolds numbers employing the open-jet concept is expected to improve the capability of generating turbulence over the entire frequency range. Thus, open-jet facilities are expected to produce higher peak aerodynamic loads than those from wind-tunnels. The Windstorm, Impact, Science, and Engineering (WISE) research group at Louisiana State University (LSU) aims to employ open-jet testing to reproduce real-wind in the laboratory; thus, facilitating the prediction of accurate aerodynamic loads on low-rise buildings. The authors tested two cubic models, at scales 1:13 and 1:26, in the open-jet and compared the roof pressure coefficients with those from a 1:100 scale wind-tunnel model.

2. METHODOLOGY IN BRIEF

The LSU open-jet is capable of large-scale testing at high Reynolds numbers along with destructive testing. Two cubic building models of 1:13 and 1:26 scale were constructed out of wooden members and sheets; the full-scale height of the cubic model is 16 m. The velocity measurements were taken at different along-wind locations in the jet facility and at different heights to choose an appropriate scale and location for testing. Besides, the mean and peak pressures are statistically computed after recording pressure-time history using pneumatic tubes and Scanivalve pressure scanners. The sensitivity of surface pressures in regards to Reynolds numbers is assessed as well.



(a)



(b)

Figure 1. Large-scale open-jet testing at LSU: (a) 1:26 scale cube, and (b) along-wind normalized velocity profile and turbulence profile.

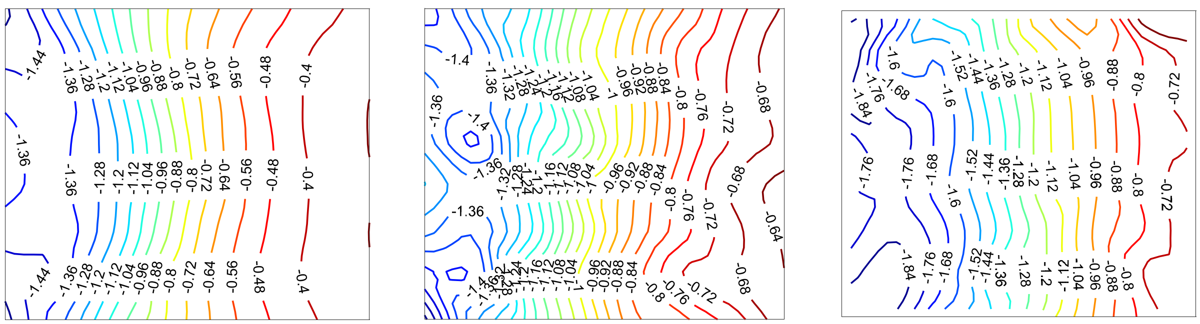
3. FINDINGS AND CONCLUSION

Figure 1 (a) introduces the LSU open-jet blowers with an adjustable flow management device placed in front. The flow management device facilitates generation of appropriate mean velocity and turbulence intensity profile corresponding to sub-urban terrain in the open-jet facility. Figure 1 (b) shows the along-wind normalized velocity profile and turbulence profile. The open-jet generated small and large-scale turbulence are in compliance with the theoretical spectra from Von-Karman, and ESDU formulations [3]. This is a momentous finding in experimental building aerodynamics. Testing in the open-jet concept assists in producing large-scale turbulence in the facility.

Table 1. Computed Reynolds numbers for different scales.

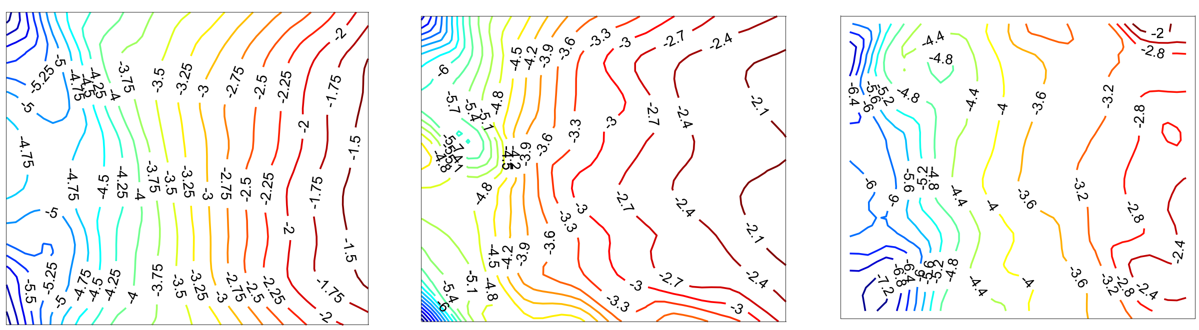
Scale	1:100 (TPU WT)	1:26 (LSU OJ)	1:13 (LSU OJ)
Reynolds number	$4.9 * 10^4$	$0.34 * 10^6$	$0.8 * 10^6$

Table 1 presents the corresponding Reynolds numbers for different scales. Figure 2 and Figure 3 manifest the trend of increase in mean and 95% quantile peak pressure coefficients along with the increase in Reynolds numbers. Besides, results demonstrate existence larger separation bubble in open-jet compared to wind-tunnels causing a gradual pressure drop downstream on the cube's roof. These encouraging results evidently bring aerodynamic testing of low-rise buildings closer to full-scale scenario. Testing of such large-scale buildings at higher Reynolds numbers in the open-jet has proven to produce higher local peak pressures. The results can have far-reaching impact in updating the existing building standards.



(a) (b) (c)

Figure 2. Mean pressure coefficients (a) 1:100 TPU Wind-tunnel, (b) 1:26 LSU open-jet, (c) 1:13 LSU open-jet



(a) (b) (c)

Figure 3. 95% quantile minimum pressure coefficients (a) 1:100 TPU Wind-tunnel, (b) 1:26 LSU open-jet, (c) 1:13 LSU open-jet

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